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SHORT COMMUNICATION

Dispersal and survival of stocked juvenile hatchery-reared Atlantic sturgeon (*Acipenser oxyrinchus*)

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Abstract. The post-stocking dispersal of juvenile Atlantic sturgeon (*Acipenser oxyrinchus* Mitchill) in the Wisłoka River (southern Poland) was investigated using biotelemetry. Thirty-five hatchery-reared juvenile *A. oxyrinchus* were tagged with radio or acoustic transmitters and tracked using mobile surveys and fixed receivers. Daily movement patterns were similar in 2009 and 2010. The sturgeon migrated with a mean speed of 1.42 km h^{-1} in 2009 and of 2.06 km h^{-1} in 2010. Migration rate was not regarded as being dependent on juvenile sturgeon size. The confirmed survival of individuals from the two field seasons differed slightly over the course of this study. Short-term survival of *A. oxyrinchus* was 86.7 and 90% in 2009 and 2010, respectively.

Keywords: reared fish, river, stocking program assessment, sturgeon, survival, telemetry

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Hatchery programs have been used for decades worldwide to compensate for declines in fish populations. Population restoration using hatchery-reared Atlantic sturgeon (*Acipenser oxyrinchus*) is one facet of recovery efforts for the Atlantic sturgeon in the Baltic Sea drainage basin (Gessner et al. 2006, Kolman et al. 2011). This species became extinct in the Baltic Sea in the twentieth century (Mamcarz 2000, Gessner et al. 2006), but it still occurs along the Atlantic coasts of Canada and the northern USA (Grunwald et al. 2008). The main cause of the disappearance of *A. oxyrinchus* was the long-term effects of anthropogenic factors that led to the transformation of aquatic ecosystems (Gessner et al. 2011). A non-channelized reach of the Wisłoka River below Dębica was identified as a recovery priority area (Wiśniewolski and Engel 2006). This section of the Wisłoka River was chosen for stocking hatchery-reared Atlantic sturgeon because it retains many natural riverine habitats. The first stocking of hatchery-reared juvenile Atlantic sturgeon in the Wisłoka River was in 2009. The first biotelemetry studies of *A. oxyrinchus* identified the habitats and migration rates of a small group of juveniles (Kapusta et al. 2011a). Based on a larger group of fish released into the Wisłoka River, the dispersion and short-term survival of juvenile sturgeon is presented.

The study was conducted along a 58-km segment of the Wisłoka River between Dębica and the river mouth near Gawłuszowice. The Wisłoka River is a right bank tributary of the Vistula River, and it is 164 km long, with a catchment area of 4110 km^2, and a mean annual discharge of 34 m^2 s^{-1}. In its upper reaches, the Wisłoka River is a shallow mountainous river with a rocky bottom. The middle and lower sections of the river drain farmlands and industrial areas. Its water flow fluctuates significantly throughout the year, and it generally reaches peak flow in July and August. Water flow data were obtained from the Institute of Meteorology and Water Management (http://pogodynka.pl/) at the monitoring station in the Pustków gauging station, only 10.5 km downstream from the stocking site. Water flow measurements at the gauging station were taken every 30 min and were averaged to hourly mean values. Water temperature was also measured daily.

Thirty-five hatchery-reared juvenile *A. oxyrinchus* were collected from the Department of Sturgeon Breeding in Pieczarki (Inland Fisheries Institute in Olsztyn, Poland). The mean body length (BL) of these fish in 2009 was 394 mm (n = 15, range 360-440 mm) and the mean body weight (BW) was 539 g (range 370-656 g), while in 2010 BL was 563 mm (n = 20, range 405-660 mm), and BW was 1730 g (range 372–3790 g). Radio-tags (153 MHz, 7-17 g, Advanced Telemetry Systems, USA) or individually coded acoustic transmitters (69 kHz, 6.4-12 g, VEMCO, Canada) were surgically implanted into the hatchery-reared juvenile *A. oxyrinchus*. Two types of transmitters were used, because the studies also included plans to verify the efficacy of the two biotelemetry methods in the much larger, deeper Vistula River. The ratio of transmitter mass to fish BW was from 1.3 to 3.0% (mean ratio 2.1%) and from 0.4 to 1.7% (mean ratio 0.9%) for juvenile Atlantic sturgeon in 2009 and 2010, respectively. Each fish was anesthetized with etomidate. A short incision was made slightly anterior to the right pelvic fin and a transmitter sterilized in ethanol was inserted into the abdominal cavity. The incision was closed with two sutures, and the wound was swabbed with Betadine. Following surgery, the fish were moved into a recovery basin and returned to the hatchery tank when normal respiration, orientation, and swimming behavior were achieved. No mortality was noted among the sturgeon at this time. The fish were transported by car to the stocking release site in oxygen-aerated tanks. On October 6, 2009 and October 7, 2010, hatchery-reared juvenile sturgeon were released into the Wisłoka River 0.5 river km downstream from the weir in Dębica.

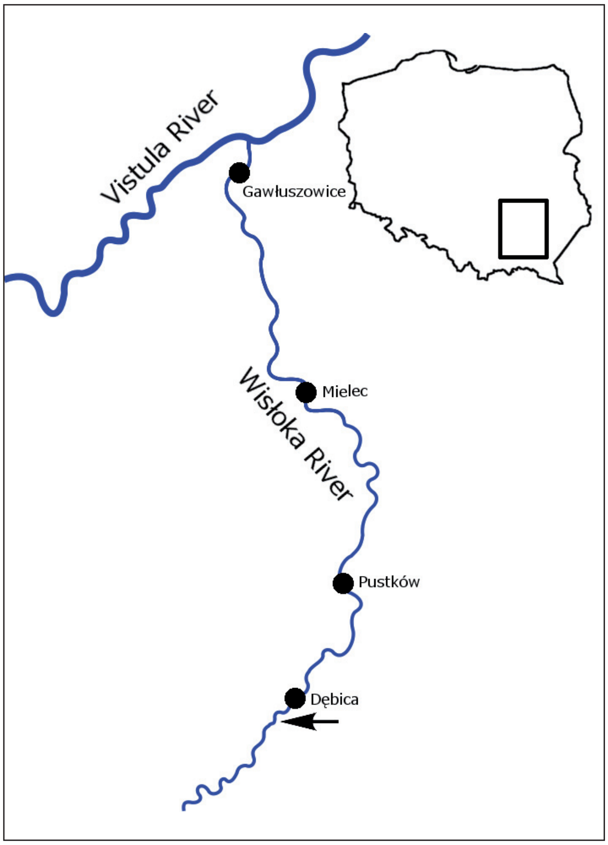

Figure 1. Study area in Wisłoka River (Poland) showing the location of the four stationary telemetry receivers (square) and stocking place (arrow).

Tagged *A. oxyrinchus* were manually tracked once daily from two inflatable boats using an ATS model R410 manual receiver with a three-element Yagi antenna and Vemco VR100 acoustic receiver coupled with a directional hydrophone. Additionally, R4500S receivers (ATS) with data loggers and four- or five-element Yagi antennas were used to continuously and automatically record radio-tagged fish migrations 24 hours per day. The tracking stations were located in Dębica (1.1 km from the stocking site),

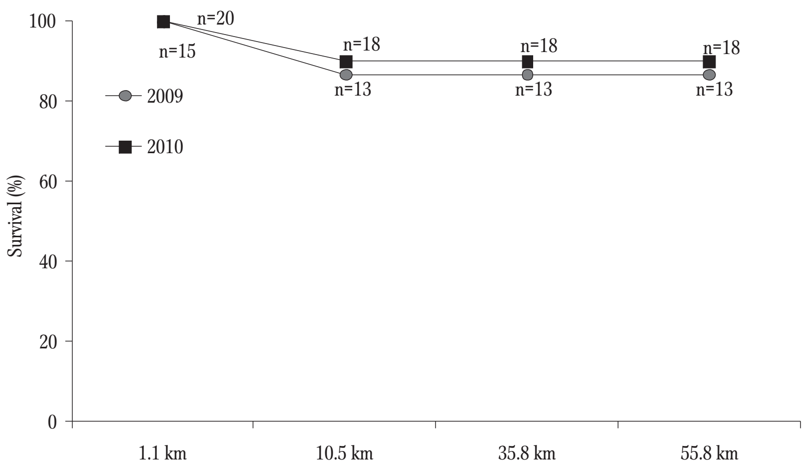

Figure 2. Proportion of tagged juvenile *A. oxyrinchus* that were recorded alive at the different receiver sites in the Wisłoka River. The number (n) of tagged sturgeon recorded at each site is given in the figure.

Pustków (10.5 km), Mielec (35.8 km), and Gawłuszowice (55.8 km). The fish with acoustic transmitters were recorded by four receiver gates (VR2W, VEMCO) deployed in the river.

The primary data analyzed in the current article were derived from specimens fitted with radio-telemetry and hydroacoustic transmitters. All migration rates were calculated from telemetry records from manual tracking and fixed-site receivers. The migration rate (body length (BL s^{-1}) and km h^{-1})) of the fish was calculated as the distance between receivers divided by time. Time was defined as the time of the last detection at the previous receiver to the time of the first detection at the next receiver. Previous studies indicate that juvenile sturgeon migrate in rivers nocturnally (Fredrich et al. 2008). Based on the length of the night during the period analyzed, the active period of the sturgeon was 13 hours per day. Differences between the migration rates of the sturgeon in both study years were analyzed with the Mann-Whitney U test. The Chi^2 test was used to determine differences in cumulative relative frequency distributions of the hour of the day of automatic receiver registrations of tagged juvenile *A. oxyrinchus* in each of the years. The mean daily water temperature in both years was compared with the Mann-Whitney U test. All statistical analyses were performed using Statistica (StatSoft Inc.).

The water temperature in the river varied significantly ($P < 0.05$) in both years of the study. A total of 816 detections and 173 relocations were registered for the hatchery-reared juvenile *A. oxyrinchus*. The short-term survival of juvenile sturgeon in 2010 was slightly higher (90%) than in 2009 (86.7%). Mortality was only noted during initial migration (Fig. 2). In each of the two years, two Atlantic sturgeon disappeared in the upper part of the river between the receivers positioned 1.1 and 10.5 km from the stocking site. In the 2009, of the 13 radio-tagged *A. oxyrinchus* that successfully migrated to the Vistula River, seven migrated from the stocking site to the river mouth in three days, three in four days, one in five days, and two in seven days. In 2010, the fates of two fish were not determined definitively. Of the eight radio-tagged and ten ultrasonic-tracked sturgeon that successfully migrated to the Vistula River, all completed the journey in two to four days (Fig. 3). Juvenile *A. oxyrinchus* moved large distances in both years and none remained in the vicinity of the release sites (<5 km) for the duration of the study. At 1 day post-release, the majority of the fish was located downstream from the release site. The mean migration rate in each of the years differed significantly statistically (Mann-Whitney U test; $P = 0.031$). The sturgeon migrated with a mean speed of 1.42 km h^{-1} in 2009 and of 2.06 km h^{-1} in 2010. The body lengths of the juvenile *A. oxyrinchus* in each of the years differed (Mann-Whitney U test; $P < 0.001$). The mean rates of downstream migration speed in relation to body length were 0.74 BL s^{-1} in 2009 and 0.97 BL s^{-1} in 2010 (Mann-Whitney U test; $P = 0.613$). Migration was predominantly nocturnal, daytime migration was also observed in each of the study years (Fig. 4). The number of detections of juvenile *A. oxyrinchus* increased at dusk, between 18:00 and 19:00, and

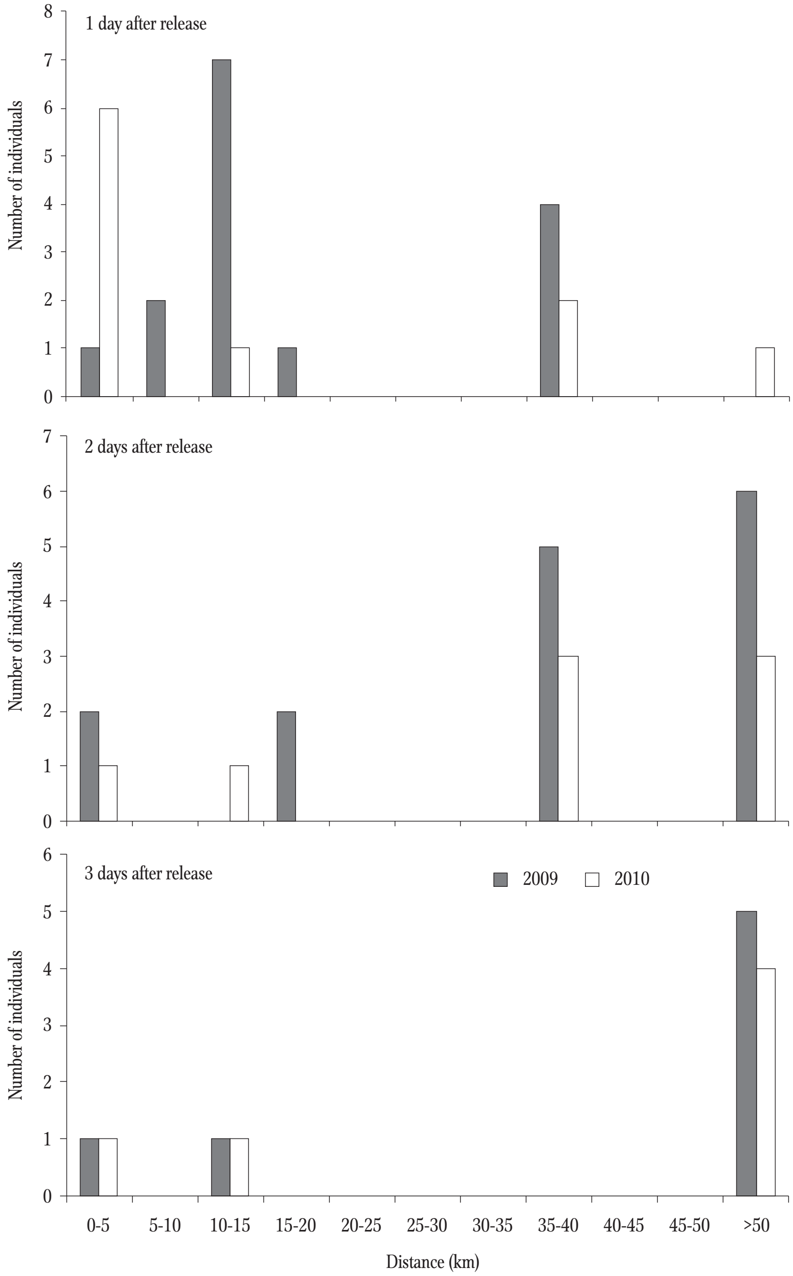

Figure 3. Dispersal of hatchery-reared juvenile *A. oxyrinchus* in the Wisłoka River. Distance is expressed as downstream movement in 5-km categories. Black bars represent data as % of individuals from 2009, and white bars represent data from 2010.

then it decreased at dawn. There was no significant difference in diel patterns of activity in either year (Chi^2 test; $P = 0.150$). The water flow in the river varied significantly ($P < 0.05$) in both years (Fig. 5). During the dispersion of sturgeon from the release site, the water flow decreased from 19 to 15.8 $m^3 s^{-1}$ in in 2009 and from 25.8 to 20 $m^3 s^{-1}$ in 2010 (Fig. 5).

River discharge has been identified as an important factor affecting the timing of surgeon migration in different rivers with increasing flows usually triggering the migration (Wishingrad et al. 2014). River flows at stocking play a crucial role in post-stocking survival. High, muddy water conditions make it difficult for fingerlings or juvenile sturgeon to find food and migrate to areas with suitable habitat. There is a need for flexibility of stocking times so that stocking can occur when river conditions are appropriate in an effort to increase survival. Stockings in the Polish mountainous rivers commonly occurred during periods of high flows, creating conditions that were not conducive to survival.

Numerous studies demonstrate that hatchery-reared fish are not necessarily equivalent to their wild counterparts (Johnsson et al. 2014), and the use of hatchery-reared fish has become a common, but controversial, conservation strategy. The efficacy of restocking as a fisheries management tool depends upon the ability of hatchery-reared juveniles to survive, grow, and reproduce in the wild after release (Thériault et al. 2011). The current study demonstrates that juvenile *A. oxyrinchus* individuals are capable of large-scale dispersal. These finding may well be a result of the relatively large fish sizes that were used. The brief time the sturgeon spend in the Wisłoka River could indicate that living conditions there are not preferable. Previous studies have shown that juvenile *A. oxyrinchus* usually remain in the rivers for two to five weeks, and then migrate via the Vistula or Oder rivers to the sea

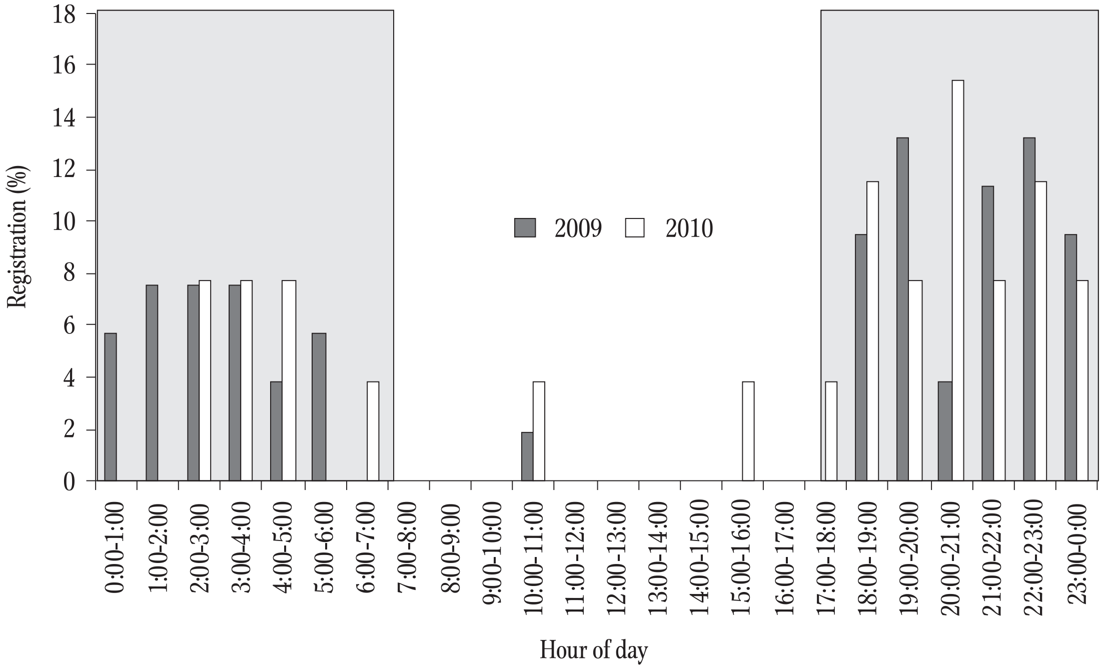

Figure 4. Diel pattern of registrations (%) on the four auto-logging receivers of the radio tagged juvenile *A. oxyrinchus*. Black bars represent data from 2009, and white bars represent data from 2010. The shaded areas indicate the period from sunset to sunrise.

(Fredrich et al. 2008, Gessner et al. 2011, Kapusta et al. 2011b). Individual movements and ranges were quite variable in the Wisłoka River. Roughly 50% of the stocked juvenile *A. oxyrinchus* emigrated out of the 58-km study area during the first three days. This differed significantly in comparison to 0+ Atlantic sturgeon in the Nanticoke River (Secor et al. 2000) and yearling or juvenile Atlantic sturgeon in the Drwęca River (Kapusta et al. 2011b). The current findings indicate quite substantial losses of hatchery-reared juvenile Atlantic sturgeon during the first days after stocking. The sturgeon remained at the release site in the Wisłoka River only one or two days before beginning to swim downstream. Previous studies report lower mortality rates of juvenile hatchery-reared *A. oxirinchus* during initial migration (Fredrich et al. 2008, Kapusta et al. 2011b).

Day-night alternation has a direct synchronizing influence on fish behavior and physiology. Diel patterns in fish activity are well documented (McCauley et al. 2014), but the diel behavior of juvenile sturgeon has not yet been well described. The results of this study revealed a clear diel pattern of sturgeon migration. These results were not surprising as light intensity strongly affects fish behavior (Lucas and Baras 2001). Diel movements are characteristic of many

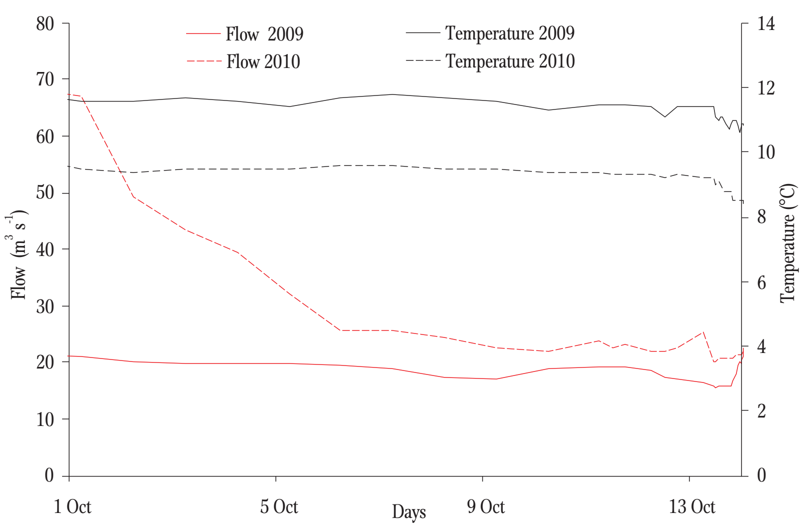

Figure 5. Daily mean water flow in the Wisłoka River during the study period in 2009-2010.

fish species, especially larvae and juveniles. Kynard and Horgan (2002) gathered evidence that Atlantic sturgeon larvae are long-distance migrants that moved at night during the first half of their migration, which reduces daytime predation risks. The more developed larvae are active both day and night (Kynard and Horgan 2002). The results of the present study indicated that juvenile Atlantic sturgeon were active at night, with a peak around sunset; so the nocturnal migration of *A. oxirinchus* could be common. Similar diel migration patterns were observed in Gulf sturgeon (*A. oxyrinchus* desatoi) in the Pensacola bay system in northwest Florida (Wrege et al. 2011).

Telemetry studies are labor intensive and costly, but they can be done with a small sample of fish. Our study demonstrates the likely benefit of using telemetry tracking as the basis for monitoring the fate of remediated *A. oxyrinchus*. This study provides valuable information on migration characteristics of hatchery-reared *A. oxyrinchus*, while it also provides unique insight into the migratory behavior of this sturgeon, on which there has been little study. The knowledge gained through the use of hatchery-reared fish will potentially aid fisheries managers in protecting appropriate habitats and river segments for the conservation and restoration of this species.

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